

# DATA ACQUISITION SYSTEM FOR NONDESTRUCTIVE EVALUATION OF SPENT NUCLEAR FUEL

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## ABSTRACT

Using complex motion control algorithms, the Multi-Axis Ultrasonic/Video Data Acquisition Inspection System is capable of a wide range of movements, including a raster scan along an arbitrary line in space (as opposed to scanning only along a fixed mechanical axis). The scans may also be programmed to follow a complex contour. The video system consists of three underwater, radiation-hardened cameras and underwater lights. A 'satellite' camera is mounted on the top of the left tower. By using both a pan-and-tilt control and zoom control, this camera provides a view of the overall operation. The other two cameras are mounted on each tower to give a remote view of the operation of each sensor head as well as a view of the material under inspection.

The scanned ultrasonic data can reveal and quantify pits, corrosion or cracks in the cans or fuel cladding, and the amount of water that may have seeped inside.

All ultrasonic tests were first proven in a laboratory setting and appropriate reference standards were constructed. Upon deployment, the system is first checked against the reference standards using multiple ultrasonic tests. By using multiple test techniques and verifying against a reference standard, QA requirements are satisfied.

## INTRODUCTION

This paper describes a Multi-Axis Ultrasonic/Video Data Acquisition System to be used at the Idaho National Engineering and Environmental Laboratory (INEEL). It was developed to nondestructively examine the condition of stored spent nuclear fuel and its containment vessels.

The INEEL has a large variety of fuel types and configurations, which are presently stored at the INEEL in water-filled storage basins. Some fuel has been stored in

basins for over 20 years. Under the terms and conditions of Gov. Phil Batt's 1995 agreement with the U.S. Department of Energy, the spent fuel must be removed from the wet storage basin to a modern dry storage facility by 2003.

The Multi-Axis Ultrasonic/Video Data Acquisition Inspection System was developed to assist in this move from wet to dry storage. The primary inspection techniques are non-destructive ultrasound inspection and video inspection. It was designed to do a number of ultrasonic tests, ranging from simple water intrusion detection to evaluation of corrosion in walls of storage containment vessels.

## SYSTEM DESCRIPTION

The system stands approximately eight feet high and is operated remotely. The entire scanning assembly (see Figure 1) is submerged in the storage basins and operated from a control console seventy-five feet away. A three-camera underwater video system is used for remote navigation and inspection. Figure 3 shows a close-up of the sensor head and one of the underwater cameras. The mechanical system is designed to operate in a basin under 20 feet of water. The system consists of three modules: a base with a turntable to support inspected materials, and two towers on each side of the base. The ultrasonic transducers supported by each tower have five axes of motion: 'X', 'Y', 'Z', 'Swivel', and 'Gimbal'.

## DESIGN DESCRIPTION

### System

The inspection system consists of two major pieces - 1) the control console and 2) the underwater scanner. The control console consists of the controlling computer, the power conditioning and uninterrupted power supply (UPS), the ultrasonic controls, data acquisition, and the motor drivers.

The controls are connected to the scanner with a bundle of 75' cables. The entire scanner, including motors and cameras, is submersible and is designed to operate under water.

The system is intended for multiple use and multiple deployment configurations. The entire system may be moved from inspection location to location. To facilitate this movement, the system is modular and may be broken down into subassemblies.

The scanner assembly (Figure 1) consists of four subassemblies, which may be disassembled for transport:

1. The scanner base
2. The left tower
3. The right tower
4. The V-Clamp fixture or Turntable



Figure 1. Scanner Assembly

The control console (see Figure 2) consists of four modules:

1. A heavy-duty cart with all of the required power conditioning and batteries.
2. A stand-up computer cart to hold the control computer and monitor.
3. A rack to house the camera equipment, the VCR and monitors, and the ultrasonic pulser/receiver. This rack has a power distribution / switch unit to control power to all devices in the rack. The power is accessible from the front for quick shutdown of any component.

4. A rack to house the motor drivers. This rack has a power distribution / switch unit as well.

As the system has been designed for multiple use scenarios, all components have been designed with an upgrade path for future modifications.



Figure 2. Control Console

### Ultrasonic System

All devices for the ultrasonic system consist of standard-technique items. The electronics and transducers are generally off-the-shelf devices. The pulser / receiver (P/R) is computer-controlled. The analog-to-digital (A/D) boards for data acquisition are 100 MHz sample-rate boards. The motion control is implemented using two six-axis controller boards. All of the interface boards are housed inside the controlling computer and connected to the rack with the appropriate cables.

The data acquisition system as explained above gives a sampling rate of up to 100 MHz, the proper amplification in both the P/R and A/D, and the ability to attenuate in the P/R. All gain settings are configured and stored using the control computer.

The ultrasonic transducers are standard units, two on each side of the scanner. The transducers on each side are chosen to provide optimum performance for a given test technique. The transducers are 'selected' by jumping BNC cables on a patch panel in the rack that houses the pulser/receiver unit. The ultrasonic pulse is driven through the 75' length of RG-59 cable from the P/R to the transducer. The pulse is received on the same transducer/cable if in pulse-echo mode or is received by another transducer/cable if in thru-transmission mode. These modes are also selected by changing configuration of the patch panel and with the control computer.

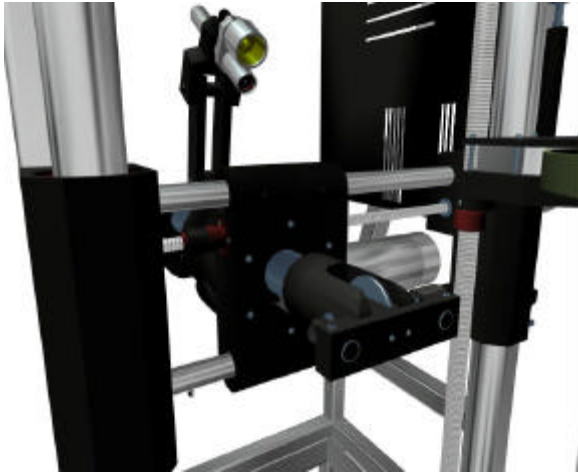


Figure 3. Sensor Head and Video Camera

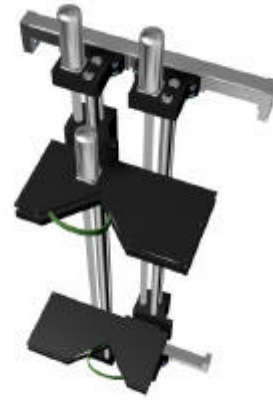


Figure 4. V - Clamp Assembly

### Motion System

The scanner has two opposing 5-axis scanning transducers (see Figure 1). Each set of transducers has the following motions, travel distances, and repeatability:

“X” (front-to-back motion)	9.2 "	±0.005 "
“Y” (Transducer in-out motion)	9.0 "	±0.005 "
“Z” (vertical motion)	61.3 "	±0.005 "
Gimbal (Transducer angle)	150°	±1°
Swivel (Transducer rotation)	349°	±1°

Each of these motions may be operated independently or in a synchronous mode, allowing both search heads/transducers to track one another.

All motions have hard stops and clutches for motor engagement with the exception of the “Z” axis (vertical motion). The “Z” axis has electronic limit switches (normally open).

### V-Clamp Fixture

The V-Clamp fixture (see Figure 4) is a holding / clamping mechanism designed to accommodate encapsulation tubes from 5/8" to 6.25" in diameter and 6" to 60" in length. The maximum weight that can be independently supported is 20 lb.

This fixture has a total of four motions - a vertical motion and a belt-clamp / cinching motion for each of the two plates. These motions are controlled *manually* at the control console using a simple pulse generation controller. The vertical motions permit adjustment of the spacing between the two clamp assemblies in order to accommodate various lengths of spent fuel containers. The clamp assemblies have electrical limit switches (normally open).

### Turntable Assembly

The turntable (see Figure 5) is designed to accommodate large cans of material. The assembly is easily removable for system configurations that do not require the turntable. The turntable is designed to support a 9" diameter by 30" tall can. The turntable will support 500 lb.

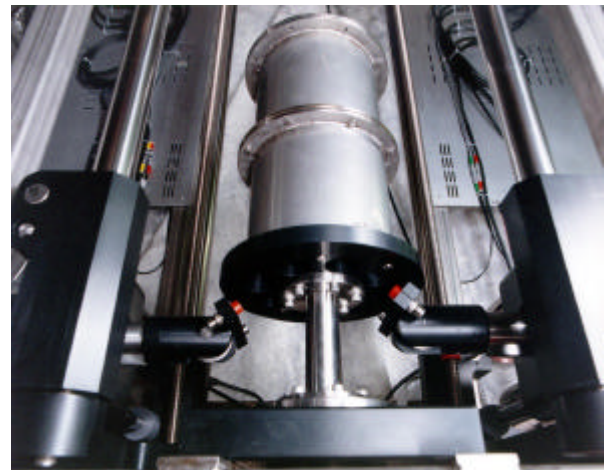


Figure 5. Turntable Assembly

### Video System

As stated previously, the primary use of the video system is for remote *navigation*, although it is capable of performing comprehensive video inspection.

There are three underwater video cameras - one on each tower and a ‘satellite’ camera clamped on the top of the scanner (see Figure 1) to provide an overall view of the operation. Each camera has its own lighting and individual control for focus, shutter speed, and light intensity. These are the camera specifications:

- One RCS-600 1" camera on each tower with one UL-210 underwater light.

Power: 12 VDC  
 Horizontal Resolution: 460 TV lines  
 Min. Illumination: 15 lux at f/1.6  
 Recommended Illumination: 200 lux at f/1.6  
 Underwater FOV: 27.2 x 35.8 degrees  
 Depth rating: 2000 feet  
 Housing Diameter: 1.00 inches  
 Housing Length: 7.57 inches

- One SVD-3 3" zoom camera with two UL-210 underwater lights. This camera is mounted on a pan-and-tilt mechanism, controlled at the workstation.

Power: 12 VDC  
 Horizontal Resolution: 460 TV lines  
 Min. Illumination: 5.9 lux at f/1.0  
 Recommended Illumination: 78 lux at f/1.0  
 Underwater FOV: 32.4 degrees to 5.7 degrees horizontal  
 Zoom: 8-48 mm, remotely controlled  
 Depth rating: 500 feet  
 Housing Diameter: 2.90 inches  
 Housing Length: 8.70 inches

The two RCS-600 cameras are placed in-line with the transducers on each scanner to provide a view of the transducers. These cameras are fixed in position.

There are two monitors at the control console with video switches that allow simultaneous viewing of any two video sources. An S-VHS VCR is included at the controls in the event that recording is desired.

The system is designed to provide an extra video signal to any other external monitor, such as a small monitor used by the operators positioning the fuel.

### Software / Data Storage

The software used to control the system is provided by Sonix, Inc. The latest version of the FLEXScan 4.0 software is used to control the data acquisition, the pulser/receiver, and all motion.

This software has the capability to scan and display the ultrasonic data in A-Scan, B-Scan, and C-scan modes. An A-Scan is an analog signal trace from an oscilloscope, whereas a B-Scan is a composite image of multiple A-Scans with color scale to represent amplitude. The C-scan is a raster scan showing signal time-of-flight or signal amplitude as a pixel color. This yields a planar image of a surface.

The motion control is very extensive, allowing scans to be made along any arbitrary line-in-space and the scan may be 'stepped' along any pre-defined contour. The contour-following ability is used to move the transducer around the canister, maintaining the face of the transducer perpendicular to the canister wall.

The software is capable of storing all information pertinent to any given scan - the scan parameters, A/D gain settings, P/R settings, and any data acquired by the scan. All ultrasound (UT) data is stored in Sonix file formats and is later transferred to CD ROM.

These are the data 'deliverables':

1. Any B-Scan, C-Scan data (scan files)
2. Any bit-mapped screen shots of A-Scan images
3. Hard copies of any of the above may be made offline
4. Simple video recording with voice annotation may be used as required

### Electronics

The controller computer contains two 6-axis, Sonix SMC6A controller boards (one for each tower). These boards interface (via 60-pin ribbon cable) to two 6-axis SMD motor driver boxes in the motor controller rack. These motor drivers use 120 VAC and provide 75 VDC, 8 Amp (*instantaneous power*) drive pulses to the stepper motors.

Due to the scan speed requirements, the "Z" axes must be driven with larger drive pulses. Two 208 VAC input, 300 VDC, 8 Amp (*instantaneous power*) output drive boxes are in the motor controller rack. These are controlled by the SMC6A boards.

The system has signal conditioners to protect the electronics from any anomalies in the facility power supply and has enough battery back-up to provide full power for approximately 4 minutes in the event of a power outage. This allows the operator to 'park' the scanner in a safe place and save all scan data.

The power conditioners need two 120 VAC, 20 AMP inputs, as well as one 208 V, 20 AMP input. This fills all power requirements of the system.

## SYSTEM PERFORMANCE

The system has been designed to characterize the integrity of stored spent fuel canisters with respect to the following characteristics:

1. Detect water intrusion
2. Detect and quantify corrosion in the canister walls
3. Image canister contents
4. Determine or verify canister dimensions

The scan times are largely dependent on the scan resolutions.

The system is a newly developed tool that has not yet been deployed for canister inspections, however, the system has been extensively tested using reference standards in a laboratory setting. The reference standards were designed to mimic possible conditions of fuel canisters to be inspected. An example of one such configuration is given in Figure 6. The reference standard shown consists of a can with two chambers. The upper chamber contains a block of corroded iron immersed in a sludge bed and water to simulate extensive corrosion in a water-filled can. The bottom chamber contains a similar block of iron in 0.5" water to simulate an intermediate state for loss of canister integrity.



Figure 6.

Figure 7 shows representative data obtained from the reference standard.

An indication of poor canister integrity is the presence of water within a can. It is relatively straightforward to determine the presence of water because a water backfill permits sound propagation within the can. This permits

tests that define the features of the can as well as the contents by through-transmission or pulse-echo methods. allows tests that rely on through transmission or pulse echo from the canister contents. For example, Figure 7(a) shows the reflected signals obtained in a raster-scan mode of the upper chamber of the reference standard. Each of the vertical lines corresponds to pulse-echo reflections from surfaces of the contents that are normal to the ultrasound pulse. The presence of these reflections is an indication of water within the can.

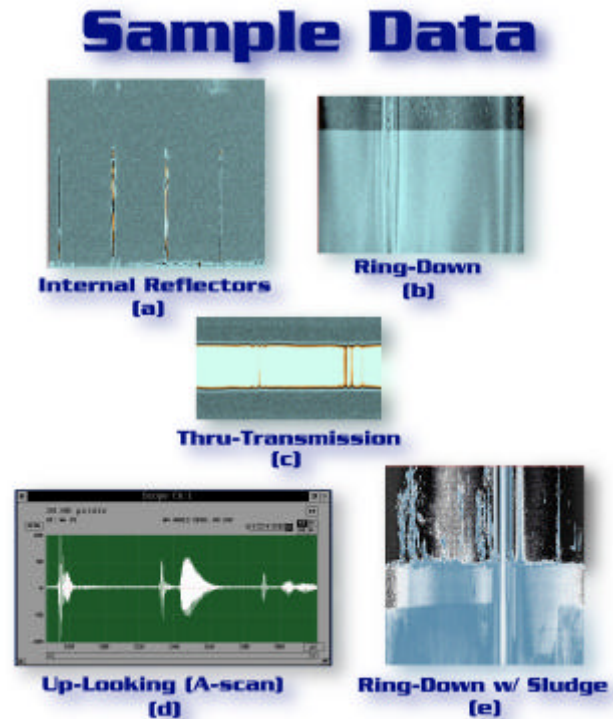


Figure 7.

Figure 7(b) shows an image acquired with ring-down techniques that measure the differential transmission of the acoustic impulse. In this example, the presence of water allows more sound to transmit into the can whereas an air void reflects most of the impulse signal. This is the most direct means of determining the presence of water in a canister. The horizontal dark band represents the air layer in the can and the horizontal white band represents the water. The scanned image also shows a set of vertical lines that correspond to the weld and other manufacturing artifacts due to canister fabrication.

Figure 7(c) shows an image acquired with through-transmission techniques that image the can contents in a shadowgram mode. The image shows two horizontal dark bands and one white band. The white band shows clean sound transmission through the entire can. This is indicative of the water above the iron block in the upper

chamber. The vertical bands in the white area are again indicative of manufacturing artifacts and the weld seam in the can. The bottom dark band represents the shadow image of the iron block and the upper dark band represents the non-transmissive air. Note that both the iron block and the air prevent the transmission of the ultrasound.

Figure 7(d) represents a quantitative measurement of the depth of water in a can. The figure shows an A-scan from a transducer pointing upwards into the can. The large signal in the center represents the reflection from the water surface. The other signals are ultrasound artifacts. This mode allows a direct reading of the time-of-flight of the sound pulse and the calculation of the water path length.

Figure 7(e) is an image of the sludge bed and water level in the upper chamber acquired by ring-down techniques. The bottom light-gray band represents the sludge bed wherein the sound impulse is absorbed. The middle gray band represents the water level. The upper dark band represents the air. The image also shows vertical streaks and a sharp vertical line. The sharp vertical line represents the weld seam in the can wall and the irregular streaks represent wet sludge adhering to the inner surface of the canister wall.

## CONCLUSIONS

To support safe spent fuel management, we have developed a multi-axis scanning ultrasonic imaging system to characterize the condition of fuel storage containers. The system features complex motion control for the automated scanning of complex surfaces and contours. The system also can scan multiple canister configurations using positioning capabilities. Performance tests have demonstrated that multiple ultrasound tests may be used to define the condition of a canister and its contents. Tests have demonstrated the detection and imaging of water in a canister. For water-filled cans, the system can image sludge, detect contents, and quantify the water depth.

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